SOLAR/1011-79/14

Solar Energy System Performance Evaluation

ALBUQUERQUE WESTERN
APARTMENT BUILDING
Albuquerque, New Mexico
October 1978 Through March 1979

U.S. Department of Energy

National Solar Heating and
Cooling Demonstration Program

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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

ALBUQUERQUE WESTERN NO. 1
ALBUQUERQUE, NEW MEXICO

OCTOBER 1978 THROUGH MARCH 1979

C. MARK FU, PRINCIPAL AUTHOR
JONATHON M. NASH, MANAGER OF SOLAR ENERGY ANALYSIS
LARRY J. MURPHY, IBM PROGRAM MANAGER

IBM CORPORATION
18100 FREDERICK PIKE
GAITHERSBURG, MARYLAND 20760

PREPARED FOR
THE DEPARTMENT OF ENERGY
OFFICE OF ASSISTANT SECRETARY FOR
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H. JACKSON HALE, PROGRAM MANAGER

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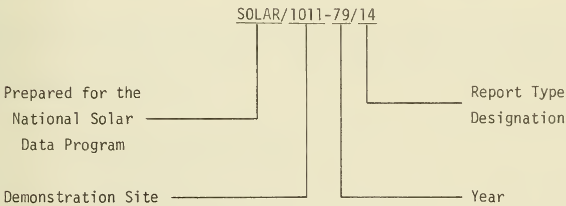
NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the Albuquerque Western No. 1 project site is designated as SOLAR/1011-79/14. The elements of this designa tion are explained in the following illustration.



- Demonstration Site Number:

  Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).

  - Solar Energy System Performance Evaluations are designated by the number 14.

- Solar Project Descriptions are designated by the number 50.

- Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth in order to achieve a substantial reduction in nonrenewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- Solar Project Description
- Design/Construction Report
- Project Costs
- Maintenance and Reliability
- Operational Experience
- Monthly Performance
- System Performance Evaluation

The International Business Machines Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The Solar Energy System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities. The Monthly Performance Report, which is the primary basis for the Solar Energy System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports represents over 8,000 discrete measurements obtained each month by the National Solar Data Network (NSDN). Documents referenced in this report are listed in Section 6,

"References". Numbers shown in brackets refer to reference numbers in Section 6. All other documents issued by the National Solar Data Program for the Albuquerque Western No. 1 solar energy system are listed in Section 7, "Bibliography".

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the Albuquerque Western No. 1 solar energy system. The analysis covers operation of the system from October 1978 through March 1979. Albuquerque Western No. 1 solar energy system provides domestic hot water (DHW) to a four-story 110-unit apartment building located in Albuquerque, New Mexico. Section 2 presents a summary of the overall system results. A system description is contained in Section 3. Analysis of the system thermal performance was accomplished using the system energy balance technique described in Section 4. Section 5 presents a detailed assessment of the individual subsystems applicable to the site.

The measurement data were collected by the NSDN [1] for the reporting period. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. This data is processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

2. SYSTEM SUMMARY

This section provides an operational summary of the performance of the solar energy system installed at the Albuquerque Western No. 1 site, located in Albuquerque, New Mexico for the period October 1978 through March 1979. This solar energy system is designed to support the domestic hot water (DHW) load. A detailed description of the Albuquerque Western No. 1 solar energy system is presented in Section 3.

2.1 Performance Summary

The site was occupied during the reporting period of October 1978 through March 1979. The solar energy system operated continuously during the period, except for an interval of 5 days in December during which the solar energy system was inoperative due to freeze damage. During the reporting period, the total incident solar energy was 415.31 million Btu, of which 91.67 million Btu were collected by the system. Solar energy satisfied 21 percent of the DHW requirements. The solar energy system provided fossil fuel energy savings of 138.87 million Btu, with an electrical energy expense of 12.27 million Btu.

A total of 415.31 million Btu of incident solar energy was measured in the plane of the collector array during the reporting period. At times when the collector array was operating there were 315.25 million Btu incident on the array. The measured average daily incident solar energy per unit area in the plane of the collector array was 1281 million Btu per square foot per day which is 32 percent below the long-term daily average of 1893 million Btu per square foot per day for the 6-month reporting period.

2.2 Conclusions

During the reporting period the collector subsystem had been modified and a shadow-band pyranometer was installed. These changes included the following: The solar collector subsystem was modified during October and work was completed on October 20, 1978. The long rows of collector panels were divided

into two subsections, each with its own tracking mechanism. The framework on the potable water transport system was also strengthened to withstand higher stress.

The collector drain line was damaged by unusually cold weather and the collector subsystem became inoperative from December 9 through December 13. To minimize future freezing potential, the two subsections of the collectors were connected in parallel with a common potable water inlet from and outlet to the storage tank. Separate drain lines were also provided for the two subsections. The solar energy system operated continuously for the rest of the reporting period.

On March 5 the pyranometer on the tracking collector system was removed and a shadow-band pyranometer was installed for measuring diffused insolation. The pyranometer placed at the collector array plane facing south remained unchanged. After analyzing the total and diffused insolation data as measured by the two currently instrumented pyranometers, it was found that since the solar collector control sensor monitors only the total insolation, the solar collectors are activated even under low direct insolation/high diffused insolation conditions. On such occasions, the collector array could radiate energy and cause energy loss from storage.

3. SYSTEM DESCRIPTION

The Albuquerque Western site is a four-story, 110-unit apartment building in Albuquerque, New Mexico. The solar energy system consists of two independently controlled systems: one system serves domestic hot water (DHW) preheating needs, the other serves to preheat hot water used in space heating. Only the DHW system is described in this report.

The solar energy system has an array of tracking collectors with a gross area of 1782 square feet. The array faces south at an angle of 35 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage. Solar energy is stored in a 2000-gallon wooden tank that contains a plastic liner. The DHW is continuously circulated throughout the building. When solar energy is insufficient to satisfy the hot water energy requirements, auxiliary heating is provided by an inline gas-fired boiler. The system, shown schematically in Figure 3-1, has three modes of operation.

Mode 1 - Collector-to-Storage: This mode activates when the collector-to-storage pump goes on. This occurs when adequate insolation is available, based on a minimum insolation intensity. Water is pumped through the collector and circulates back to storage.

Mode 2 - DHW Preheating: This mode activates when the storage-to-heat-exchanger pump goes on. This occurs when storage is at or above a predetermined temperature level. Supply water is preheated through the heat exchanger and fed into the boiler.

Mode 3 - Auxiliary Hot Water Heating: This mode activates when the natural gas-fired boiler is required to "top out" the continuously circulating hot water in order to obtain the preset temperature of the supply water (usually 140°F). This occurs when the solar energy system can no longer meet the preset temperature.

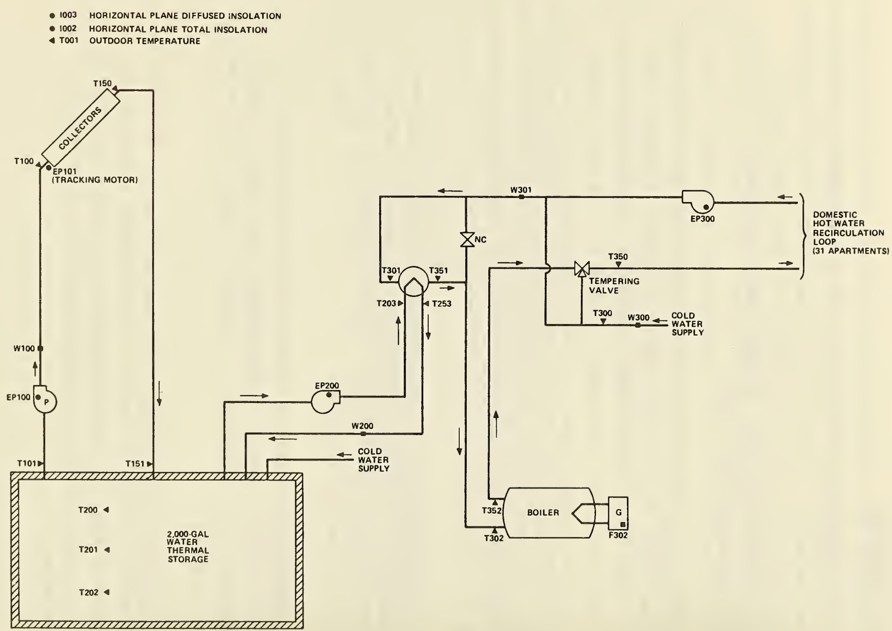


FIGURE 3-1. SOLAR ENERGY SYSTEM SCHEMATIC
ALBUQUERQUE WESTERN NO. 1

4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the Albuquerque Western No. 1 solar energy system is evaluated by calculating a set of primary performance factors which are based on those proposed in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system is then evaluated based on the efficiency of the system in transferring these energies. A list of all performance factors and their definitions are presented in Appendix A.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. These data are first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for the calculation of the daily and monthly performance of each component subsystem. The performance factor equations for this site are listed in Appendix B.

Each month, as appropriate, a summary of overall performance of the Albuquerque Western No. 1 site and a detailed subsystem analysis is published. These monthly reports for the period covered by this Solar Energy System Performance Evaluation, October 1978 through March 1979, are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

5. PERFORMANCE ASSESSMENT

The performance of the Albuquerque Western No. 1 solar energy system has been evaluated for the October 1978 through March 1979 time period. Two perspectives were taken in this assessment: The first views the overall system in which the total solar energy collected, the system load, the measured values for solar energy used, and system solar fraction are presented. In addition, the solar energy system coefficient of performance (COP) at both the system and subsystem level has been presented. The second view presents a more in-depth look at the performance of individual subsystems. Details relating to the performance of the collector array and storage subsystems are presented first, followed by details pertaining to the domestic hot water (DHW) subsystem. Included in this section are all parameters pertinent to the operation of each individual subsystem.

In addition to the overall system and subsystem analysis, this report also describes the equivalent energy savings contributed by the solar energy system. The overall system and individual subsystem energy savings are presented in section 5.5.

The performance assessment of any solar energy system is highly dependent on the prevailing weather conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore, before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical weather parameters has been provided.

5.1 Weather Conditions

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the Albuquerque Western No. 1 site during the reporting period are presented in Table 5-1.

TABLE 5-1. WEATHER CONDITIONS

ALBUQUERQUE WESTERN NO. 1

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA[1] (Btu/Ft^2)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
OCT	1544	2132	61	58	N.A.	N.A.	N.A.	N.A.
NOV	1052	1239	47	45	N.A.	N.A.	N.A.	N.A.
DEC	1129	1618	34	36	N.A.	N.A.	N.A.	N.A.
JAN	1052	1695	32	35	N.A.	N.A.	N.A.	N.A.
FEB	1411	1928	40	40	N.A.	N.A.	N.A.	N.A.
MAR	1500	2143	47	46	N.A.	N.A.	N.A.	N.A.
TOTAL					N.A.	N.A.	N.A.	N.A.
AVERAGE	1281	1893	43	43	N.A.	N.A.	N.A.	N.A.

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(1) In collector array plane and azimuth, unless otherwise indicated in Section 5.1.
N.A. denotes not applicable data

Also presented in Table 5-1 are the corresponding long-term average monthly values of the measured weather parameters. These data are taken from Reference Monthly Environmental Data for Systems in the National Solar Data Network [4]. A complete yearly listing of these values for the site is given in Appendix C.

During the October 1978 through March 1979 reporting period, the average daily incident solar energy on the collector array was 1281 Btu per square foot per day. This was below the estimated average daily solar radiation for this geographical area during the reporting period of 1893 Btu per square foot per day. (Global solar radiation is used for this comparison.) The average ambient temperature during the reporting period was 43°F, the same as the long-term average for the reporting period.

5.2 System Thermal Performance

The thermal performance of a solar energy system is a function of the total solar energy collected and applied to the system load. The total system load is the sum of the useful energy delivered to the loads (excluding losses in the system), including both solar and auxiliary thermal energies. The portion of the total load provided by solar energy is defined to be the solar fraction of the load.

The thermal performance of the Albuquerque Western No. 1 solar energy system is presented in Table 5-2. This performance assessment is based on the 6-month period from October 1978 through March 1979. During the reporting period, a total of 91.67 million Btu of solar energy was collected and the total system load was 248.43 million Btu. The measured amount of solar energy delivered to the load subsystem was 83.33 million Btu. The measured system solar fraction was 21 percent.

Figure 5-1 illustrates the flow of solar energy from the point of collection to the various points of consumption and loss for the reporting period. The numerical values account for the quantity of energy corresponding with the

TABLE 5-2. SYSTEM THERMAL PERFORMANCE SUMMARY

ALBUQUERQUE WESTERN NO. 1

MONTH	SOLAR ENERGY COLLECTED (Million Btu)	SYSTEM LOAD (Million Btu)	SOLAR ENERGY USED (Million Btu)		SOLAR FRACTION (%)	
			EXPECTED	MEASURED	EXPECTED	MEASURED
OCT	25.11	32.81	*	23.44	*	49
NOV	10.54	37.25	*	10.27	*	23
DEC	10.95	44.73	*	8.91	*	15
JAN	10.31	46.80	*	8.31	*	13
FEB	18.95	41.30	*	17.01	*	29
MAR	15.81	45.54	*	15.39	*	25
TOTAL	91.67	248.43	*	83.33		
AVERAGE	15.28	41.41	*	13.89	*	21

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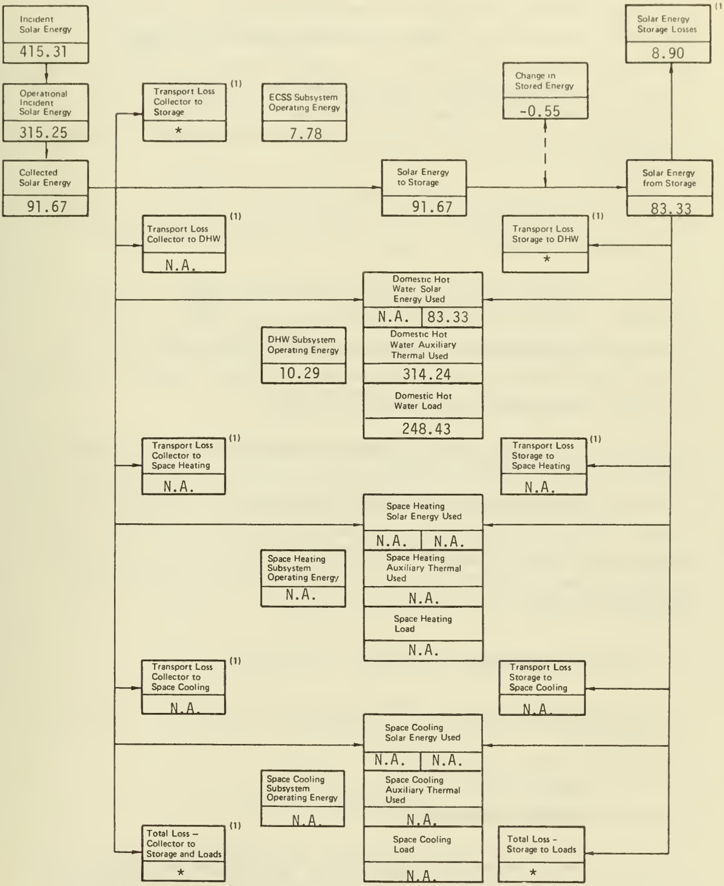
* Denotes unavailable data

FIGURE 5-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART – SUMMARY

ALBUQUERQUE WESTERN NO. 1



* Denotes Unavailable Data

N.A. denotes not applicable data

(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

transport, operation, and function of each major element in the Albuquerque Western No. 1 solar energy system for the total reporting period. The collected solar energy was set equal to the energy delivered to storage, because of sensor resolution problems in the collector-to-storage loop. However, the error introduced by this assumption is believed small (less than 10 percent) due to a very high flow rate in the loop. The problem is under investigation by IBM/Boeing.

Solar energy distribution flowcharts for each month of the reporting period are presented in Appendix D.

Table 5-3 summarizes solar energy distribution and provides a percentage breakdown. For the period October 1978 through March 1979, the load subsystem consumed 91 percent of the energy collected, and 10 percent was lost. (A net of one percent was extracted from stored energy.) Appendix E contains the monthly solar energy percentage distributions.

The solar energy coefficient of performance (COP) is indicated in Table 5-4. The COP provides a numerical value for the relationship of solar energy collected, transported or used, and the energy required to perform the transition. The greater the COP value, the more efficient the subsystem. The solar energy system at Albuquerque Western No. 1 functioned at a reporting period weighted average COP value of 6.79 for the period of October 1978 through March 1979.

5.3 Subsystem Performance

The Albuquerque Western No. 1 solar energy installation may be divided into two subsystems:

1. Collector Array and Storage
2. Domestic Hot Water (DHW)

Each subsystem is evaluated and analyzed by the techniques defined in Section 4 to produce monthly performance reports. This section presents the results

TABLE 5-3. SOLAR ENERGY DISTRIBUTION - SUMMARY

ALBUQUERQUE WESTERN NO. 1

91.67 million Btu	100%	TOTAL SOLAR ENERGY COLLECTED
83.33 million Btu	91%	SOLAR ENERGY TO LOADS
83.33 million Btu	91%	SOLAR ENERGY TO DHW SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
8.90 million Btu	10%	SOLAR ENERGY LOSSES
8.90 million Btu	10%	SOLAR ENERGY LOSS FROM STORAGE
* million Btu	%	SOLAR ENERGY LOSS IN TRANSPORT
* million Btu	%	COLLECTOR TO STORAGE LOSS
N.A. million Btu	%	COLLECTOR TO LOAD LOSS
N.A. million Btu	%	COLLECTOR TO DHW LOSS
N.A. million Btu	%	COLLECTOR TO SPACE HEATING LOSS
N.A. million Btu	%	COLLECTOR TO SPACE COOLING LOSS
* million Btu	%	STORAGE TO LOAD LOSS
* million Btu	%	STORAGE TO DHW LOSS
N.A. million Btu	%	STORAGE TO SPACE HEATING LOSS
N.A. million Btu	%	STORAGE TO SPACE COOLING LOSS
-0.56 million Btu	-1%	SOLAR ENERGY STORAGE CHANGE

* Denotes unavailable data

N.A. denotes not applicable data

TABLE 5-4. SOLAR ENERGY SYSTEM COEFFICIENT OF PERFORMANCE

ALBUQUERQUE WESTERN NO. 1

MONTH	SOLAR ENERGY SYSTEM COP	COLLECTOR ARRAY SUBSYSTEM SOLAR COP	DOMESTIC HOT WATER SUBSYSTEM SOLAR COP	SPACE HEATING SUBSYSTEM SOLAR COP	SPACE COOLING SUBSYSTEM SOLAR COP
OCT	7.71	15.99	15.95	N.A.	N.A.
NOV	4.87	10.23	9.51	N.A.	N.A.
DEC	6.06	10.63	20.25	N.A.	N.A.
JAN	5.40	8.81	22.46	N.A.	N.A.
FEB	8.38	13.25	28.35	N.A.	N.A.
MAR	7.40	10.20	29.04	N.A.	N.A.
WEIGHTED AVERAGE	6.79	11.78	18.56	N.A.	N.A.

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N.A. denotes not applicable data

of integrating the monthly data for the two subsystems for the period October 1978 through March 1979.

5.3.1 Collector Array and Storage Subsystem

5.3.1.1 Collector Array

Collector array performance for the Albquerque Western No. 1 site is presented in Table 5-5. The total incident solar radiation on the collector array for the reporting period was 415.31 million Btu. During the period the collector loop was operating the total insolation amounted to 315.25 million Btu. The total collected solar energy for the period was 91.67 million Btu, resulting in a collector array efficiency of 22 percent, based on total incident insolation. Solar energy delivered from the collector array to storage was 91.67 million Btu. Operating energy required by the collector loop was 7.78 million Btu.

Collector array efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system a part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; therefore, the energy is not collected. In this approach, collector array performance is described by comparing the collected solar energy to the incident solar energy. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s/Q_i$$

where: η_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

TABLE 5-5. COLLECTOR ARRAY PERFORMANCE

ALBUQUERQUE WESTERN NO. 1

MONTH	INCIDENT SOLAR ENERGY (Million Btu)	COLLECTED SOLAR ENERGY (Million Btu)	COLLECTOR ARRAY EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY (Million Btu)	OPERATIONAL COLLECTOR ARRAY EFFICIENCY (%)
OCT	85.32	25.11	29	66.80	38
NOV	56.26	10.54	19	39.00	27
DEC	62.38	10.95	18	39.42	28
JAN	58.09	10.31	18	46.26	22
FEB	70.41	18.95	27	60.61	31
MAR	82.85	15.81	19	63.16	25
TOTAL	415.31	91.67		315.25	
AVERAGE	69.22	15.28	22	52.54	29

S002

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Efficiency" in Table 5-5.

The second approach assumes the efficiency is based upon the incident solar energy during periods of collection only.

Evaluation of collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yields operational collector efficiency. Operational collector efficiency, η_{co}, is computed as follows:

$$\eta_{co} = Q_s/(Q_{oi} \times \frac{A_p}{A_a})$$

where: Q_s = collected solar energy

Q_{oi} = operational incident energy

A_p = gross collector area (product of the number of collectors and the total envelope area of one unit)

A_a = gross collector array area (total area perpendicular to the solar flux vector including all mounting, connecting and transport hardware)

Note: The ratio $\frac{A_p}{A_a}$ is typically 1.0 for most collector array configurations.

This latter efficiency term is not the same as collector efficiency as represented by the ASHRAE Standard 93-77 [5]. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined

from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 5-5.

5.3.1.2 Storage

Storage performance data for the Albuquerque Western No. 1 site for the reporting period is shown in Table 5-6. Results of analysis of solar energy losses during transport and storage is shown in Table 5-7.

During the reporting period, total solar energy delivered to storage was 91.67 million Btu. There were 83.33 million Btu delivered from storage to the DHW subsystem. Energy loss from storage was 8.90 million Btu. This loss represented 10 percent of the energy delivered to storage. The storage efficiency was 90 percent: This is calculated as the ratio of the sum of the energy removed from storage and the change in stored energy, to the energy delivered to storage. The average storage temperature for the period was 139°F.

Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage and change in stored energy. The ratio of the sum of energy from storage and the change in stored energy, to the energy to storage is defined as storage efficiency, η_s. This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si}$$

where:

ΔQ = change in stored energy. This is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value)

TABLE 5-6. STORAGE PERFORMANCE

ALBUQUERQUE WESTERN NO. 1

MONTH	ENERGY TO STORAGE (Million Btu)	ENERGY FROM STORAGE (Million Btu)	CHANGE IN STORED ENERGY (Million Btu)	STORAGE EFFICIENCY (%)	STORAGE AVERAGE TEMPERATURE (°F)	EFFECTIVE STORAGE HEAT LOSS COEFFICIENT (Btu/Hr -- °F)
OCT	25.11	23.44	0.01	93	144	*
NOV	10.54	10.27	0.09	98	137	*
DEC	10.95	8.91	-0.37	78	134	*
JAN	10.31	8.31	0.32	84	136	*
FEB	18.95	17.01	-0.05	89	142	*
MAR	15.81	15.39	-0.55	94	140	*
TOTAL	91.67	83.33	-0.55			
AVERAGE	15.28	13.89	-0.09	90	139	*

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* Denotes unavailable data

TABLE 5-7 SOLAR ENERGY LOSSES – STORAGE AND TRANSPORT
ALBUQUERQUE WESTERN NO. 1

	MONTH						
	OCT	NOV	DEC	JAN	FEB	MAR	TOTAL
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million Btu)	25.1	10.5	11.0	10.3	19.0	15.8	91.7
2. SE TO STORAGE (million Btu)	25.1	10.5	11.0	10.3	19.0	15.8	91.7
3. LOSS – COLLECTOR TO STORAGE (%) $\frac{1-2}{1}$	*	*	*	*	*	*	*
4. CHANGE IN STORED ENERGY (million Btu)	0.01	0.09	-0.37	0.32	-0.05	-0.55	-0.55
5. SOLAR ENERGY – STORAGE TO DHW SUBSYSTEM (million Btu)	23.4	10.3	8.9	8.3	17.0	15.4	83.3
6. SOLAR ENERGY – STORAGE TO SPACE HEATING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
7. SOLAR ENERGY – STORAGE TO SPACE COOLING SUBSYSTEM (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
8. LOSS FROM STORAGE (%) $\frac{2-(4+5+6+7)}{2}$	7	1	22	16	11	6	10
9. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million Btu)	23.4	10.3	8.9	8.3	17.0	15.4	83.3
10. LOSS – STORAGE TO HWSE (%) $\frac{5-9}{5}$	*	*	*	*	*	*	*
11. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million Btu)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
12. LOSS – STORAGE TO HSE (%) $\frac{6-11}{6}$	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

* Denotes unavailable data
N.A. denotes not applicable data

Q_{so} = energy from storage. This is the amount of energy extracted by the load subsystem from the primary storage medium

Q_{si} = energy to storage. This is the amount of energy (both solar and auxiliary) delivered to the primary storage medium

In the Albuquerque Western No. 1 solar energy system, because of the high flow rate in the storage/heat exchanger loop, the temperature measurements at the storage side of the heat exchanger are not reliable for computing the energy removed from storage. Since the heat exchanger is physically located in close proximity to the storage tank, it is included in the storage subsystem for the performance evaluation, so that the temperature measurements at the load side of the heat exchanger can be used for improved accuracy in the performance factor calculation of the storage subsystem.

5.3.2 Domestic Hot Water (DHW) Subsystem

The DHW subsystem performance for the Albuquerque Western No. 1 site for the reporting period is shown in Table 5-8. The DHW subsystem consumed 83.33 million Btu of solar energy and 314.24 million Btu of auxiliary fossil fuel energy to satisfy a hot water load of 248.43 million Btu. The solar fraction of this load was 21 percent.

The performance of the DHW subsystem is described by comparing the amount of solar energy supplied to the subsystem with the total energy required by the subsystem. The total energy required by the subsystem consists of both solar energy and auxiliary thermal energy.

The DHW load is defined as the amount of energy required to raise the mass of water delivered by the DHW subsystem between the temperature at which it entered the subsystem and its delivery temperature. The DHW solar fraction is defined as the portion of the DHW load which is supported by solar energy.

TABLE 5-8. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

ALBUQUERQUE WESTERN NO. 1

MONTH	DOMESTIC HOT WATER LOAD (Million Btu)	ENERGY CONSUMED (Million Btu)				SOLAR FRACTION (%)
		SOLAR	AUXILIARY THERMAL	AUXILIARY		
				ELECTRICAL	FOSSIL	
OCT	32.81	23.44	33.08		49.62	49
NOV	37.25	10.27	52.14		76.45	23
DEC	44.73	8.91	62.34		90.41	15
JAN	46.80	8.31	65.90		94.80	13
FEB	41.30	17.01	47.85		72.58	29
MAR	45.54	15.39	52.93		75.02	25
TOTAL	248.43	83.33	314.24	N.A.	458.88	
AVERAGE	41.41	13.89	52.37	N.A.	76.48	21

S002

N.A. denotes not applicable data

5.4 Operating Energy

Measured values of the Albuquerque Western No. 1 solar energy system and subsystem operating energy for the reporting period are presented in Table 5-9. A total of 18.07 million Btu of operating energy was consumed by the entire system during the reporting period.

Operating energy for a solar energy system is defined as electrical energy that is used to support the subsystems without affecting their thermal state. Total operating energy for the Albuquerque Western No. 1 solar energy system consists of energy collection and storage subsystem (ECSS) operating energy and DHW subsystem operating energy. In reference with the system schematic (Figure 3-1) the ECSS operating energy includes electrical energy required to operate the pump in the collector/storage loop (EP100) and the electrical energy required to operate the tracking motor which drives the tracking mechanism of the collector banks (EP101). The DHW subsystem operating energy includes electrical energy required to operate the pump in the heat exchanger loop (EP200) and the pump in the DHW recirculation loop (EP300).

5.5 Energy Savings

Energy savings for the Albuquerque Western No. 1 site for the reporting period are presented in Table 5-10. For this time period, the total savings were 138.87 million Btu, with a monthly average of 23.15 million Btu. An electrical energy expense of 12.27 million Btu was incurred during the reporting period towards operating solar energy transporting pumps.

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to provide solar energy to the load subsystems is subtracted from the solar energy contribution to determine net savings.

The auxiliary source at the Albuquerque Western No. 1 consists of natural gas-fired boilers. These units are considered to be 60 percent efficient for computational purposes.

TABLE 5-9 . OPERATING ENERGY

ALBUQUERQUE WESTERN NO. 1

MONTH	ENERGY COLLECTION AND STORAGE OPERATING ENERGY (Million Btu)	DOMESTIC HOT WATER OPERATING ENERGY (Million Btu)	SPACE HEATING OPERATING ENERGY (Million Btu)	SPACE COOLING OPERATING ENERGY (Million Btu)	TOTAL SYSTEM OPERATING ENERGY (Million Btu)
OCT	1.57	2.46	N.A.	N.A.	4.03
NOV	1.03	2.05	N.A.	N.A.	3.08
DEC	1.03	1.43	N.A.	N.A.	2.46
JAN	1.17	1.34	N.A.	N.A.	2.51
FEB	1.43	1.49	N.A.	N.A.	2.92
MAR	1.55	1.52	N.A.	N.A.	3.07
TOTAL	7.78	10.29	N.A.	N.A.	18.07
AVERAGE	1.30	1.72	N.A.	N.A.	3.01

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N.A. denotes not applicable data

TABLE 5-10. ENERGY SAVINGS

ALBUQUERQUE WESTERN NO. 1

MONTH	SOLAR ENERGY USED (Million Btu)	SOLAR ENERGY SAVINGS ATTRIBUTED TO (Million Btu)						SOLAR OPERATING ENERGY (Million Btu)	ENERGY SAVINGS (Million Btu)	
		SPACE HEATING		DOMESTIC HOT WATER		SPACE COOLING				
		ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
OCT	23.44	N.A.	N.A.	-3.04	39.07	N.A.	N.A.	3.04	-3.04	39.07
NOV	10.27	N.A.	N.A.	-2.11	17.12	N.A.	N.A.	2.11	-2.11	17.12
DEC	8.91	N.A.	N.A.	-1.47	14.85	N.A.	N.A.	1.47	-1.47	14.85
JAN	8.31	N.A.	N.A.	-1.54	13.84	N.A.	N.A.	1.54	-1.54	13.84
FEB	17.01	N.A.	N.A.	-2.03	28.34	N.A.	N.A.	2.03	-2.03	28.34
MAR	15.39	N.A.	N.A.	-2.08	25.65	N.A.	N.A.	2.08	-2.08	26.56
TOTAL	83.33	N.A.	N.A.	-12.27	138.87	N.A.	N.A.	12.27	-12.27	138.87
AVERAGE	13.89	N.A.	N.A.	-2.05	23.15	N.A.	N.A.	2.05	-2.05	23.15

N.A. denotes not applicable data

S002

6. REFERENCES

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3. E. Streed, et. al., Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

4. Mears, J. C. Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

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6.# Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-78/10, Department of Energy, Washington, D.C., (October 1978).

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9.# Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-79/01, Department of Energy, Washington, D.C., (January 1979).

10.# Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-79/02, Department of Energy, Washington, D.C., (February 1979).

11.# Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-79/03, Department of Energy, Washington, D.C., (March 1979).

Copies of these reports may be obtained from Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

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3. Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-78/07, Department of Energy, Washington, D.C., (July 1978).

4. Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-78/08, Department of Energy, Washington, D.C., (August 1978).

5. Monthly Performance Report, Albuquerque Western No. 1, SOLAR/1011-78/09, Department of Energy, Washington, D.C., (September 1978).

APPENDIX A

DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy collected with respect to the energy available to be collected.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy incident on the collector array during the time that the collector loop is active (attempting to collect energy).

- COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.

- COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy collected to the total solar energy incident on the collector array. It should be emphasized that this efficiency factor is for the collector array, and available energy includes the energy incident on the array when the collector loop is inactive. This efficiency must not be confused with the more common collector efficiency figures which are determined from instantaneous test data obtained during steady-state operation of a single collector unit. These efficiency figures are often provided by collector manufacturers or presented in technical journals to characterize the functional capability of a particular collector design. In general, the collector panel maximum efficiency factor will be significantly higher than the collector array efficiency reported here.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.

- ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).

- STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.

- STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.

- ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.

- AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary energy supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.

- ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow into and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem.

- HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.

- SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.

- OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.

- AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- AUXILIARY FOSSIL FUEL (HWAF) is the amount of fossil fuel energy supplied directly to the subsystem.

- ELECTRICAL ENERGY SAVINGS (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- FOSSIL FUEL SAVINGS (HWSVF) is the estimated difference between the fossil fuel energy requirements of the alternative conventional system (carrying the full load) and the actual fossil fuel energy requirements of the subsystem.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow into the subsystem. The average building temperature is tabluated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.

- SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.

- SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- OPERATING ENERGY (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the system.

- AUXILIARY THERMAL USED (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- AUXILIARY ELECTRICAL FUEL (HAE) is the amount of electrical energy supplied directly to the subsystem.

- ELECTRICAL ENERGY SAVINGS (HSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- BUILDING TEMPERATURE (TB) is the average heated space dry bulb temperature.

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS

ALBUQUERQUE WESTERN NO. 1

I. INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds. This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: The total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{AREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in Btu per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{M100} \times \Delta H] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in Btu/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

$$\Delta H = \bar{c}_p\ \Delta T$$

where $\bar{c}_p$ is the average specific heat, in Btu/(lb_m-°F), of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

For electrical power, a general example is

$$\text{ECSS OPERATING ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by electrical equipment in kilowatts and the two factors (1/60) and 3413 correct the data to Btu/min.

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document was prepared by an interagency committee of the Government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each integration process, therfore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

II. EQUATIONS USED IN MONTHLY PERFORMANCE REPORT

NOTE: MEASUREMENT NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 3-1.

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma\ T001 \times \Delta\tau$$

DAYTIME AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma\ T001 \times \Delta\tau$$

FOR $\pm$ 3 HOURS FROM SOLAR NOON

INCIDENT SOLAR ENERGY PER UNIT AREA (Btu/FT^2)

$$SE = (1/60) \times \Sigma\ I002 \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON ARRAY (BTU)

$$SEA = (1/60) \times \Sigma[I002 \times CLAREA] \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma[I002 \times CLAREA] \times \Delta\tau$$

WHEN THE COLLECTOR LOOP IS ACTIVE

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma[M100 \times HWD(T150, T100)] \times \Delta\tau$$

WHERE: M100 IS THE COLLECTOR FLUID MASS FLOW RATE AND HWD IS A FUNCTION CALCULATING CHANGE IN FLUID ENTHALPY OVER THE RANGE T150-T100.

COLLECTED SOLAR ENERGY PER UNIT AREA (BTU/FT^2)

$$SEC = \Sigma[M100 \times HWD(T150, T100)/CLAREA] \times \Delta\tau$$

COLLECTOR ARRAY EFFICIENCY (PERCENT)

$$CAREFF = (SECA/SEA) \times 100$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = (56.88) \times \Sigma[EP100 + EP101 \times (110/507)] \times \Delta\tau$$

STORAGE TEMPERATURE (°F)

$$TST = (1/60) \times \Sigma[(T200 + T201 + T202)/3] \times \Delta\tau$$

ENERGY TO STORAGE (BTU)

$$STEI = \Sigma[M100 \times HWD(T151, T101)] \times \Delta\tau$$

ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma[M301 \times HWD(T351, T301)] \times \Delta\tau$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STOCAP \times (TST \times RHO \times CP - TST_p \times RHO_p \times CP_p)$$

WHERE: THE SUBSCRIPT p INDICATES VALUES TAKEN FROM A PREVIOUS REFERENCE HOUR

STORAGE EFFICIENCY (PERCENT)

$$STEFF = [(STECH + STEO)/STEI] \times 100$$

ENERGY DELIVERED TO LOAD FROM ECSS (BTU)

$$CSEO = STEO$$

HOT WATER CONSUMPTION (GALLONS)

$$HWCSM = \Sigma\ WD300 \times \Delta\tau$$

WHERE: WD300 IS THE TIME DERIVATIVE OF THE TOTALIZING FLOWMETER

HOT WATER LOAD (BTU)

$$HWL = \Sigma[M300 \times HWD(T350, T300)] \times \Delta\tau$$

HOT WATER SOLAR ENERGY (BTU)

$$HWSE = CSEO$$

HOT WATER AUXILIARY THERMAL (BTU)

$$HWAT = \Sigma[M301 \times HWD(T352, T302)] \times \Delta\tau$$

HOT WATER AUXILIARY FOSSIL FUEL ENERGY (BTU)

$$HWAF = \Sigma\ FCONST \times F302C \times \Delta\tau$$

WHERE: FCONST IS THE ENERGY EQUIVALENT OF ONE UNIT OF FOSSIL FUEL AND F302C IS THE TIME DERIVATIVE OF THE TOTALIZING FLOWMETER. A VALUE OF 1044 IS USED FOR FCONST.

HOT WATER SOLAR FRACTION (PERCENT)

$$HWSR = 100 \times HWSE/(HWAT + HWSE)$$

SUPPLY WATER TEMPERATURE (°F) - MASS FLOW WEIGHTED

$$TSW = \frac{\Sigma\ T300 \times M300 \times \Delta\tau}{\Sigma\ M300 \times \Delta\tau}$$

HOT WATER TEMPERATURE (°F) - MASS FLOW WEIGHTED

$$THW = \frac{\Sigma\ T350 \times M301 \times \Delta\tau}{\Sigma\ M301 \times \Delta\tau}$$

HOT WATER OPERATING ENERGY (BTU)

$$HWOPE = \Sigma\ 56.88 \times (EP200 + EP300) \times \Delta\tau$$

HOT WATER ELECTRICAL ENERGY SAVINGS (BTU)

$$HWSVE = -(\Sigma\ 56.88 \times EP200) - CSPOE$$

HOT WATER FOSSIL FUEL ENERGY SAVINGS (BTU)

$$HWSVF = HWSE/HWFEFF$$

WHERE: HWFEFF IS THE HOT WATER HEATER THERMAL EFFICIENCY (LONG-TERM AVERAGE). A VALUE OF 0.6 IS USED WHERE SPECIFIC DATA IS NOT AVAILABLE.

SYSTEM LOAD (BTU)

$$SYSL = HWL$$

SYSTEM SOLAR FRACTION (PERCENT)

$$SFR = HWSFR$$

SOLAR ENERGY TO LOAD (BTU)

$$SEL = HWSE$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = CSOPE + HWOPE$$

SYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$AXT = HWAT$$

SYSTEM AUXILIARY FOSSIL FUEL ENERGY SAVINGS (BTU)

$$AXF = HWAF$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE

TOTAL FOSSIL FUEL ENERGY SAVINGS (BTU)

TSVF = HWSVF

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + HWAF + SECA

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

This appendix contains a table which lists the long-term average weather conditions for each month of the year for this site.

SITE: ALB. WESTERN 55. LOCATION: ALBUQUERQUE NM

ANALYST: M FU FDRIVE NO.: 1.

COLLECTOR TILT: 35.00 (DEGREES) COLLECTOR AZIMUTH: 0.0 (DEGREES)

LATITUDE: 35.05 (DEGREES) RUN DATE: 6/04/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1591.	1018.	0.63979	1.666	1695.	924	0	35.
FEB	2032.	1342.	0.66048	1.437	1928.	700	0	40.
MAR	2581.	1766.	0.68420	1.213	2143.	595	0	46.
APR	3125.	2227.	0.71260	1.021	2274.	282	6	56.
MAY	3486.	2540.	0.72878	0.896	2277.	56	67	65.
JUN	3624.	2680.	0.73963	0.843	2261.	0	291	75.
JUL	3548.	2489.	0.70151	0.869	2162.	0	425	79.
AUG	3257.	2290.	0.70294	0.964	2208.	0	360	77.
SEP	2773.	1973.	0.71145	1.135	2240.	7	160	70.
OCT	2189.	1549.	0.70735	1.377	2132.	218	7	58.
NOV	1692.	1136.	0.67122	1.620	1839.	615	0	45.
DEC	1466.	929.	0.63358	1.742	1618.	893	0	36.

LEGEND:

HOBAR ==> MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.

HBAR ==> MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.

KBAR ==> RATIO OF HBAR TO HOBAR.

RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).

SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * HBAR) IN BTU/DAY-FT2.

HDD ==> NUMBER OF HEATING DEGREE DAYS PER MONTH.

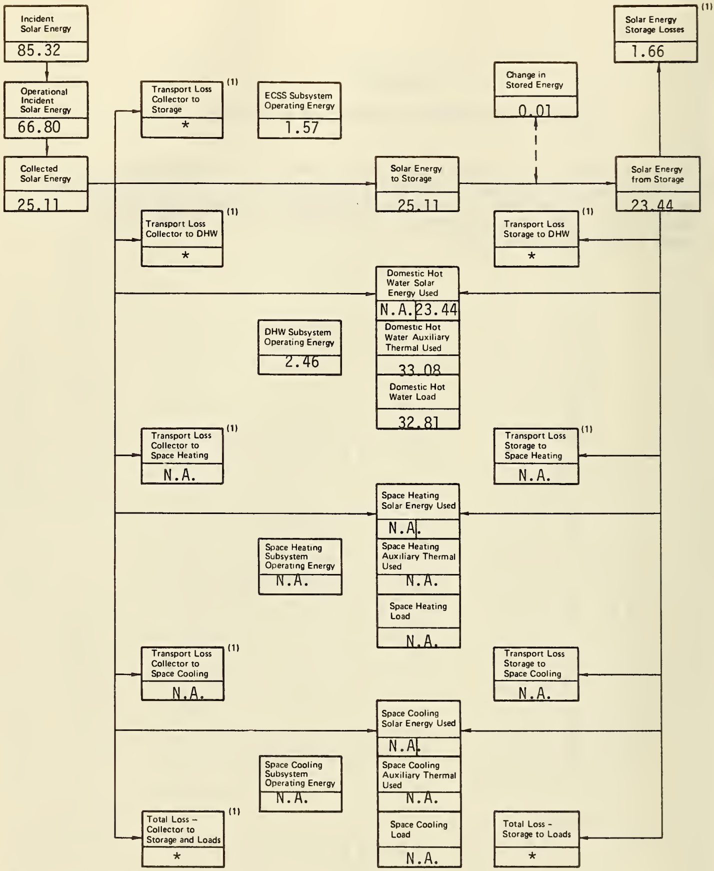
CDD ==> NUMBER OF COOLING DEGREE DAYS PER MONTH.

TBAR ==> AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.

APPENDIX D

MONTHLY SOLAR ENERGY DISTRIBUTION FLOWCHARTS

The flowcharts in this appendix depict the quantity of solar energy corresponding to each major component or characteristic of the Albuquerque Western No. 1 solar energy system for 6 months of the reporting period. Each monthly flowchart represents a solar energy balance as the total input equals the total output.

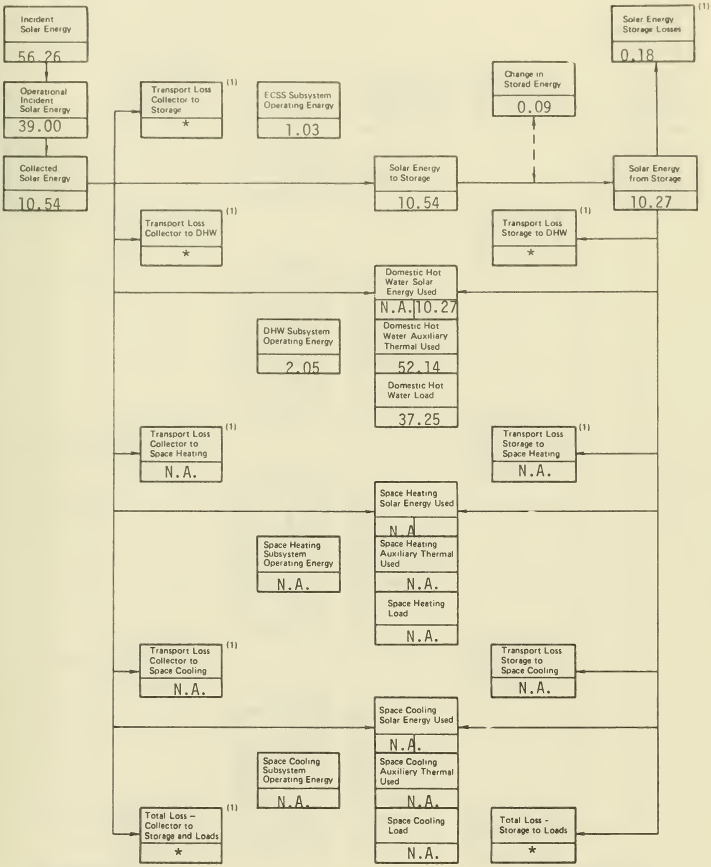


* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-1. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - OCTOBER 1978

ALBUQUERQUE WESTERN NO. 1



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

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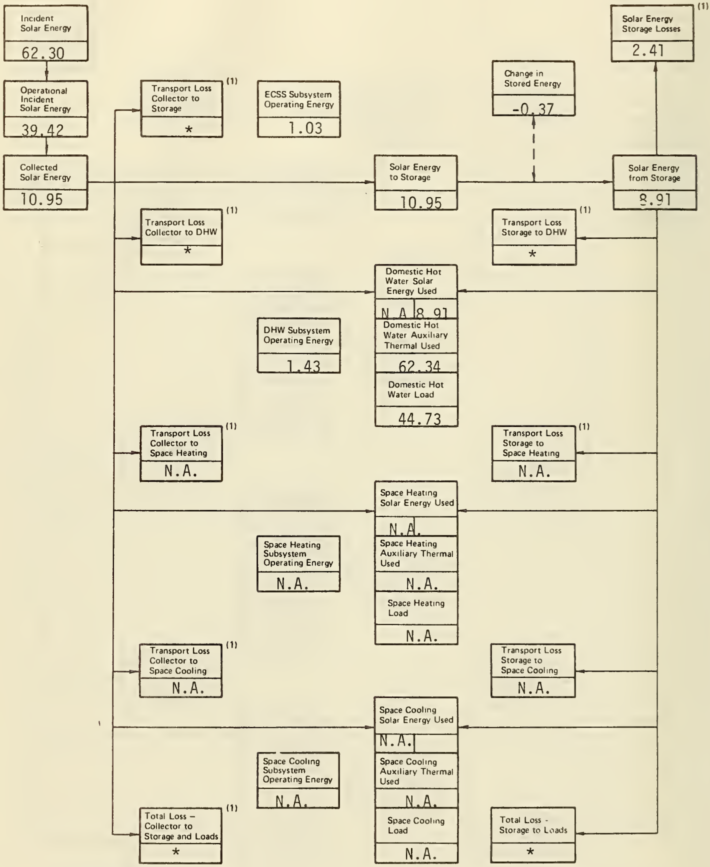
FIGURE D-2. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - NOVEMBER 1978

ALBUQUERQUE WESTERN NO. 1

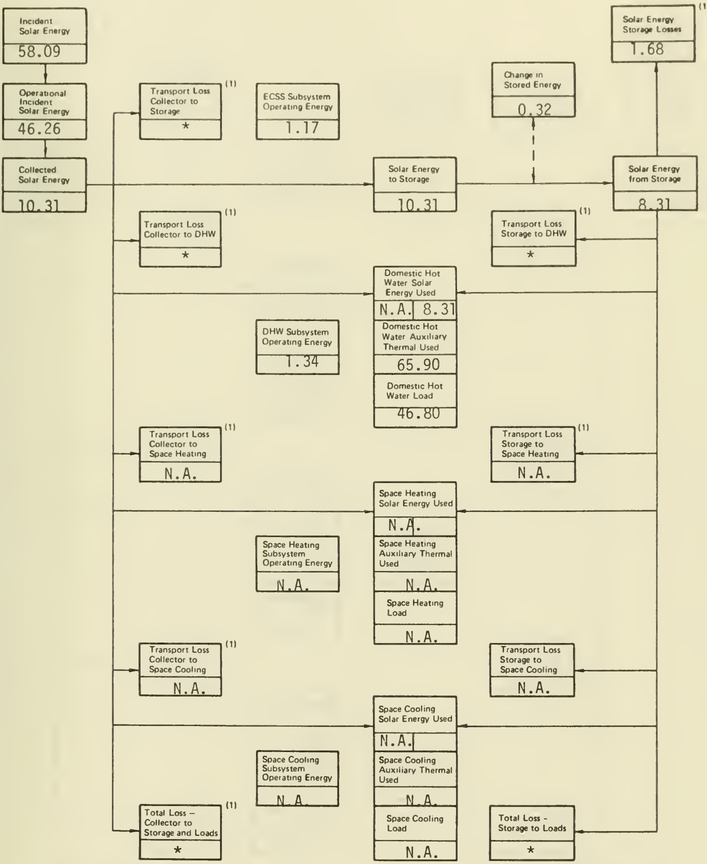


* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-3. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - DECEMBER 1978

ALBUQUERQUE WESTERN NO. 1

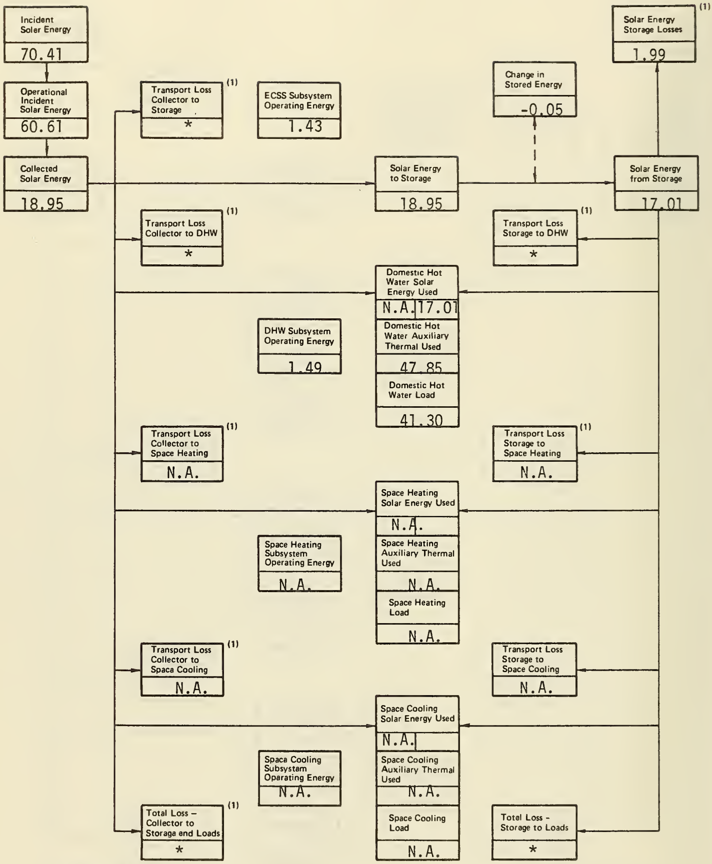


* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

S002

FIGURE D-4. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - JANUARY 1979

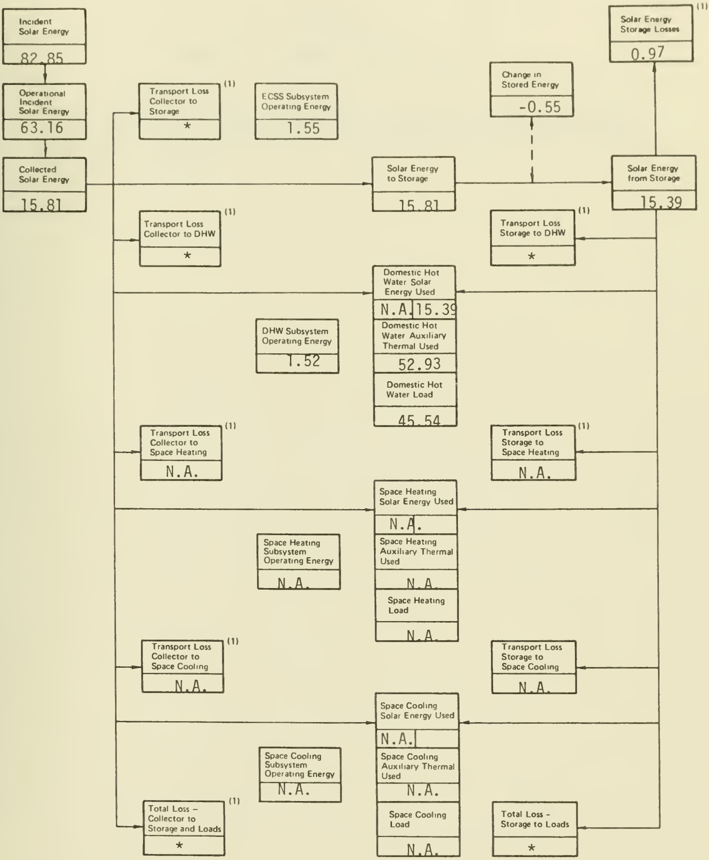
ALBUQUERQUE WESTERN NO. 1



* Denotes Unavailable Data
N.A. denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

FIGURE D-5. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - FEBRUARY 1979

ALBUQUERQUE WESTERN NO. 1



* Denotes Unavailable Data
N A denotes not applicable data
(1) May contribute to offset of space heating load (if known – see text for discussion)

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FIGURE D-6. SOLAR ENERGY (MILLION BTU) DISTRIBUTION FLOWCHART - MARCH 1979

ALBUQUERQUE WESTERN NO. 1

APPENDIX E

MONTHLY SOLAR ENERGY DISTRIBUTIONS

The data tables provided in this appendix present an indication of solar energy distribution, intentional and unintentional, in the Albuquerque Western No. 1 solar energy system. Tables are provided for 6 months of the reporting period.

TABLE E-1. SOLAR ENERGY DISTRIBUTION - OCTOBER 1978

ALBUQUERQUE WESTERN NO. 1

- 25.11 million Btu / 100% TOTAL SOLAR ENERGY COLLECTED
  - 23.44 million Btu / 93% SOLAR ENERGY TO LOADS
    - 23.44 million Btu / 93% SOLAR ENERGY TO DHW SUBSYSTEM
    - N.A. million Btu / % SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
    - N.A. million Btu / % SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
  - 1.66 million Btu / 7% SOLAR ENERGY LOSSES
    - 1.66 million Btu / 7% SOLAR ENERGY LOSS FROM STORAGE
    - * million Btu / % SOLAR ENERGY LOSS IN TRANSPORT
      - * million Btu / % COLLECTOR TO STORAGE LOSS
      - N.A. million Btu / % COLLECTOR TO LOAD LOSS
        - N.A. million Btu / % COLLECTOR TO DHW LOSS
        - N.A. million Btu / % COLLECTOR TO SPACE HEATING LOSS
        - N.A. million Btu / % COLLECTOR TO SPACE COOLING LOSS
      - * million Btu / % STORAGE TO LOAD LOSS
        - * million Btu / % STORAGE TO DHW LOSS
        - N.A. million Btu / % STORAGE TO SPACE HEATING LOSS
        - N.A. million Btu / % STORAGE TO SPACE COOLING LOSS
  - 0.01 million Btu / 0% SOLAR ENERGY STORAGE CHANGE

* Denotes Unavailable Data

N.A. denotes not applicable data

TABLE E-2. SOLAR ENERGY DISTRIBUTION - NOVEMBER 1978
ALBUQUERQUE WESTERN NO. 1

10.54	100%	million Btu	TOTAL SOLAR ENERGY COLLECTED
10.27	97%	million Btu	SOLAR ENERGY TO LOADS
10.27	98%	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
N.A.	%	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A.	%	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
0.18	2%	million Btu	SOLAR ENERGY LOSSES
0.18	2%	million Btu	SOLAR ENERGY LOSS FROM STORAGE
*	%	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
*	%	million Btu	COLLECTOR TO STORAGE LOSS
N.A.	%	million Btu	COLLECTOR TO LOAD LOSS
N.A.	%	million Btu	COLLECTOR TO DHW LOSS
N.A.	%	million Btu	COLLECTOR TO SPACE HEATING LOSS
N.A.	%	million Btu	COLLECTOR TO SPACE COOLING LOSS
*	%	million Btu	STORAGE TO LOAD LOSS
*	%	million Btu	STORAGE TO DHW LOSS
N.A.	%	million Btu	STORAGE TO SPACE HEATING LOSS
N.A.	%	million Btu	STORAGE TO SPACE COOLING LOSS
0.09	1%	million Btu	SOLAR ENERGY STORAGE CHANGE

* Denotes Unavailable Data
N.A. denotes not applicable data

TABLE E-3. SOLAR ENERGY DISTRIBUTION - DECEMBER 1978

ALBUQUERQUE WESTERN NO. 1

10.95 million Btu	100%	TOTAL SOLAR ENERGY COLLECTED
8.91 million Btu	81%	SOLAR ENERGY TO LOADS
8.91 million Btu	81%	SOLAR ENERGY TO DHW SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A. million Btu	%	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
2.41 million Btu	22%	SOLAR ENERGY LOSSES
2.41 million Btu	22%	SOLAR ENERGY LOSS FROM STORAGE
* million Btu	%	SOLAR ENERGY LOSS IN TRANSPORT
* million Btu	%	COLLECTOR TO STORAGE LOSS
N.A. million Btu	%	COLLECTOR TO LOAD LOSS
N.A. million Btu	%	COLLECTOR TO DHW LOSS
N.A. million Btu	%	COLLECTOR TO SPACE HEATING LOSS
N.A. million Btu	%	COLLECTOR TO SPACE COOLING LOSS
* million Btu	%	STORAGE TO LOAD LOSS
* million Btu	%	STORAGE TO DHW LOSS
N.A. million Btu	%	STORAGE TO SPACE HEATING LOSS
N.A. million Btu	%	STORAGE TO SPACE COOLING LOSS
-0.37 million Btu	-3%	SOLAR ENERGY STORAGE CHANGE

* Denotes Unavailable Data

N.A. denotes not applicable data

TABLE E-4. SOLAR ENERGY DISTRIBUTION - JANUARY 1979

ALBUQUERQUE WESTERN NO. 1

10.31	100%	million Btu	TOTAL SOLAR ENERGY COLLECTED
8.31	81%	million Btu	SOLAR ENERGY TO LOADS
8.31	81%	million Btu	SOLAR ENERGY TO DHW SUBSYSTEM
N.A.	%	million Btu	SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
N.A.	%	million Btu	SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
1.66	16%	million Btu	SOLAR ENERGY LOSSES
1.68	16%	million Btu	SOLAR ENERGY LOSS FROM STORAGE
*	%	million Btu	SOLAR ENERGY LOSS IN TRANSPORT
*	%	million Btu	COLLECTOR TO STORAGE LOSS
N.A.	%	million Btu	COLLECTOR TO LOAD LOSS
N.A.	%	million Btu	COLLECTOR TO DHW LOSS
N.A.	%	million Btu	COLLECTOR TO SPACE HEATING LOSS
N.A.	%	million Btu	COLLECTOR TO SPACE COOLING LOSS
*	%	million Btu	STORAGE TO LOAD LOSS
*	%	million Btu	STORAGE TO DHW LOSS
N.A.	%	million Btu	STORAGE TO SPACE HEATING LOSS
N.A.	%	million Btu	STORAGE TO SPACE COOLING LOSS
0.32	3%	million Btu	SOLAR ENERGY STORAGE CHANGE

* Denotes Unavailable Data

N.A. denotes not applicable data

TABLE E-5. SOLAR ENERGY DISTRIBUTION - FEBRUARY 1979

ALBUQUERQUE WESTERN NO. 1

18.95 million Btu / 100% TOTAL SOLAR ENERGY COLLECTED

- 17.01 million Btu / 90% SOLAR ENERGY TO LOADS
  - 17.01 million Btu / 90% SOLAR ENERGY TO DHW SUBSYSTEM
  - N.A. million Btu / % SOLAR ENERGY TO SPACE HEATING SUBSYSTEM
  - N.A. million Btu / % SOLAR ENERGY TO SPACE COOLING SUBSYSTEM
- 1.99 million Btu / 10% SOLAR ENERGY LOSSES
  - 1.99 million Btu / 10% SOLAR ENERGY LOSS FROM STORAGE
  - * million Btu / % SOLAR ENERGY LOSS IN TRANSPORT
    - * million Btu / % COLLECTOR TO STORAGE LOSS
    - N.A. million Btu / % COLLECTOR TO LOAD LOSS
      - N.A. million Btu / % COLLECTOR TO DHW LOSS
      - N.A. million Btu / % COLLECTOR TO SPACE HEATING LOSS
      - N.A. million Btu / % COLLECTOR TO SPACE COOLING LOSS
    - * million Btu / % STORAGE TO LOAD LOSS
      - * million Btu / % STORAGE TO DHW LOSS
      - N.A. million Btu / % STORAGE TO SPACE HEATING LOSS
      - N.A. million Btu / % STORAGE TO SPACE COOLING LOSS
- -0.05 million Btu / 0% SOLAR ENERGY STORAGE CHANGE

* Denotes Unavailable Data

N.A. denotes not applicable data

TABLE E-6. SOLAR ENERGY DISTRIBUTION - MARCH 1979

ALBUQUERQUE WESTERN NO. 1

15.81 million Btu / 100% TOTAL SOLAR ENERGY COLLECTED

15.39 million Btu / 97% SOLAR ENERGY TO LOADS

15.39 million Btu / 97% SOLAR ENERGY TO DHW SUBSYSTEM

N.A. million Btu / % SOLAR ENERGY TO SPACE HEATING SUBSYSTEM

N.A. million Btu / % SOLAR ENERGY TO SPACE COOLING SUBSYSTEM

0.97 million Btu / 6% SOLAR ENERGY LOSSES

0.97 million Btu / 6% SOLAR ENERGY LOSS FROM STORAGE

* million Btu / % SOLAR ENERGY LOSS IN TRANSPORT

* million Btu / % COLLECTOR TO STORAGE LOSS

N.A. million Btu / % COLLECTOR TO LOAD LOSS

N.A. million Btu / % COLLECTOR TO DHW LOSS

N.A. million Btu / % COLLECTOR TO SPACE HEATING LOSS

N.A. million Btu / % COLLECTOR TO SPACE COOLING LOSS

* million Btu / % STORAGE TO LOAD LOSS

* million Btu / % STORAGE TO DHW LOSS

N.A. million Btu / % STORAGE TO SPACE HEATING LOSS

N.A. million Btu / % STORAGE TO SPACE COOLING LOSS

-0.55 million Btu / -3% SOLAR ENERGY STORAGE CHANGE

* Denotes Unavailable Data

N.A. denotes not applicable data

*U.S. GOVERNMENT PRINTING OFFICE: 1980-640-189/4231. Region 4.